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WIND POWER USAGE IN EUROPE?

Doctor A. Th. Gross

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16. Abstract

The development of wind power technology has lead to basic discoveries which will make standardized large-scale production possible. Its economical use is regarded as a possible extra source of electrical energy for already existing systems, since there is an abundance of wind in the plains stretches of Central Europe. Equipment cost for system-sized, self regulating wind power machines which now produce a respectable 100 to 300 kilowatts, are estimated at about 600 to 700 marks per kilowatt in large-scale production. In those areas which still have no electricity, underdeveloped countries for instance, an individual wind machine could well compete with the diesel engine.

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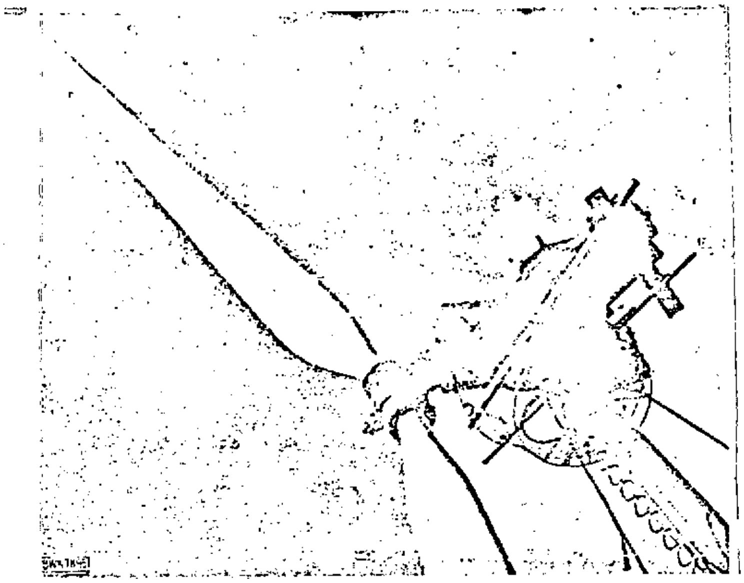
WIND POWER USAGE IN EUROPE?[1]

Doctor A. Th. Gross[2]



An excellent insight into European wind power work was afforded by the annual meeting of the Wind Power Study Group on the 12th and 13th of June which German representatives of the power commission, industry and the Technical Institute, and famous experts from Denmark, England, France, India, Spain, and the USA attended. The meeting started off with a tour of the 100-kilowatt experimental facility built by the study group in Stoetten near Geislinger/Steige. The assembled members of the study group and a group of experts under the leadship of Professor A. Weise, engineer, Technical Institute of Stuttgart, joined in reading theses of foreign experts. /1*

Experimental Wind Power Facility at Stoetten

The Study Group, founded in 1949, set as its primary goal the construction of a wind power facility large enough to test the question of wind power exploitation for Central European requirements on a large scale. As a result of competition, the 100 kilowatt facility was begun and erected by the Wind Power Development Community, Registered Union, Stuttgart, founded in 1955 for this purpose on the suggestion of Doctor U. Huetter[3], engineer, of Kirchheim/Teck.

[1]Results of the yearly meeting of the Wind Power Study Group, Registered Union, Stuttgart.
[2]Engineer, V. D. I. Essen
[3]See also the background report on the 10th partial meeting of the wind power conference, 1951, in Rio de Janiero by U. Huetter: The Development of Wind Power Facilities for Producing Electricity in Germany. BWK 6 (1964) m,270/78.
*Numbers in the margin indicate pagination in the foreign text.

This facility, figures 1 to 3, is probably presently the largest wind power unit in the world, becuase it is not the height at which it might be installed which determines the actual capacity of the unit, but the area covered by the blades, in this case 900 square meters, or almost one tenth of a hectare. For the unit in Stoetten the specific designed capacity, that is, the area covered by the blades, was deliberately chosen to be small. This was because the requirement for as stable a power output as possible was raised on the part of the power supply company in consideration for the problems of load distribution.

The electronic switching unit developed by the AEG makes automatic operation possible. This program was developed in a pilot study with an Allgaier A. C. unit of 10 kilowatts in cooperation with the Wind Power Study Group, the Hamburg Electric Works, Incorporated, and the Swabain Power Supply Company ES, Stuttgart. This program has made possible the fully automatic injection of electrical energy into the public system for almost two years now. The coupling of a wind-driven asynchronous or synchronous generator with a power consumer system can be regarded as technically feasible only to the extent that a fully automatic switching system within the system can be gradually introduced also in other countries. This requires nothing less than that wind-power facilities to produce public electric power can be left to themselves without any kind of servcing under all weather and system conditions.

The unit in Stoetten was built as an experimental unit, and this makes it possible, as planned, to test repair operations and procedures of different kinds. It is also possible to follow a regulated program at different levels of power with a constant load, to whatever extent this is necessary. The revolution rate in this case for the wind velocity at which power begins to flow is, at u/v = 20, the highest obtained until now under such conditions.

One should also note that the unit began to run when the wind velocity was only 2.5 meters per second. The blades, with their 17 meter radius and their fiberglass-reinforced polyester resin fabric, showed their particular suitability during a storm where they turned for several hours after the assembly was knocked crooked on its tower anchor, and did not break.

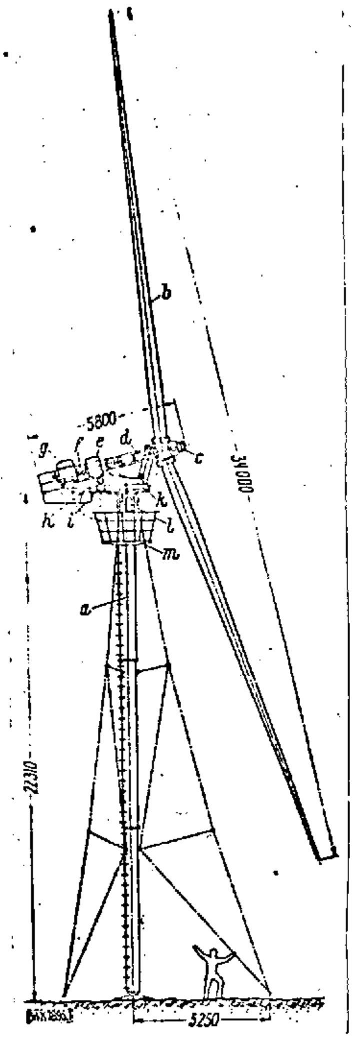


Figure 1. 100 Kilowatt Test Unit at Stoetten, Wind Power Study Group. Wheel diameter: 34 meters; blade surface: 900 square meters; nominal rpm: 42 rpm; rpm capacity, no-load: 20; for nominal load: 10; pylon: 10; height: 22 meters. a, Girder tower; b, fiberglass reinforced plastic blades (half cardan blade suspension); c, drive shaft and hub with races and roller bearings; d, main shaft with blade adjustment drive (hydraulic piston with 7 to 10 atmospheres oil pressure); e, three-stage Voith spur-gear drive (1:35.8); f, v-belt drive; g, AEG 100 kilowatts synchronous generator, 1500 rpm, 50 Hz, auto-regulated by magnetic booster and cables; h, directional motor; i, directional drive; k, welded machine housing, oil reservoir for control hydraulics; 1, input to load current (4 coil rings) and control current (22 coil rings) conduits; m, mast platform.

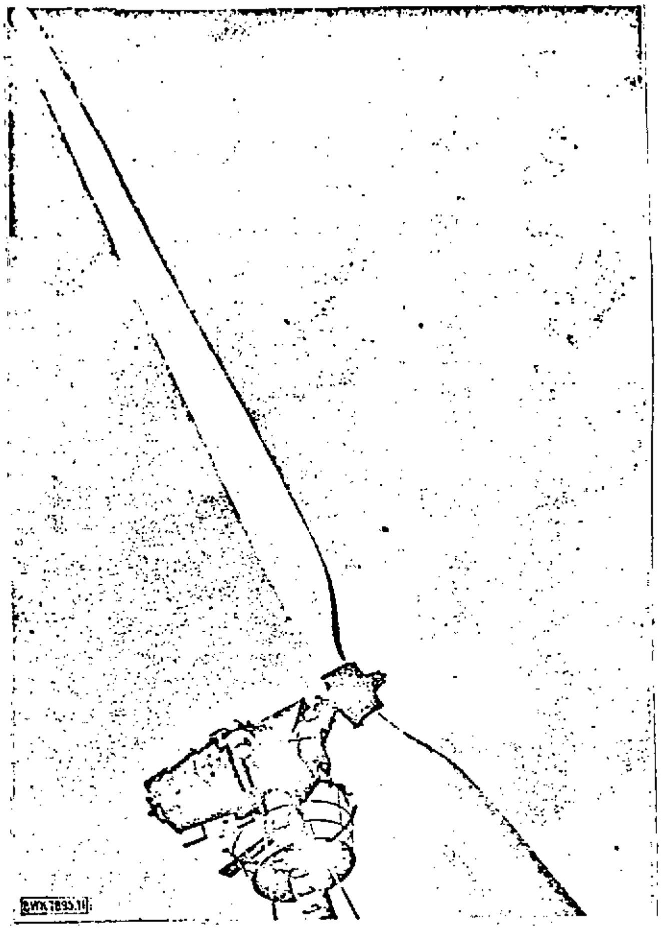


Figure 2. Experimental Unit in Stoetten Before it Commenced Operations in 1957. See also the title picture which shows the unit while it is being demonstrated.

Operating Performance of Fast-Moving Wind-Power Machines

The papers of the experts' meeting dealt with this general topic[4]. The most important result of the meeting was the agreement evidenced in statements of a Danish, an English, and a French speaker, when they viewed future prospects for wind power machines favorably, and not only to supply isolated consumers from individual units, but also, under certain conditions, to help feed existing systems. These two types of application must, however, be regarded separately. The first case will be concerned with relatively small power loads and as uncomplicated, strong, and /3 cheap construction as possible. This will require an additional energy storage facility and will have to compete with diesel power units. In the second case, units of a certain minimum size are required for which, as for the Stoetten unit, a concomitantly larger outlay for control, independent parallel switching, etc. will be necessary and also practical, even more so since batteries are not adequate to cover times when the wind is weak. This development is being promoted in Denmark, Germany, England, and France. The basic relationships, possibilities, and overall outlines are shown in Figure 4.

[4]All papers are in the text of the announcements of the Wind Power Study Group.

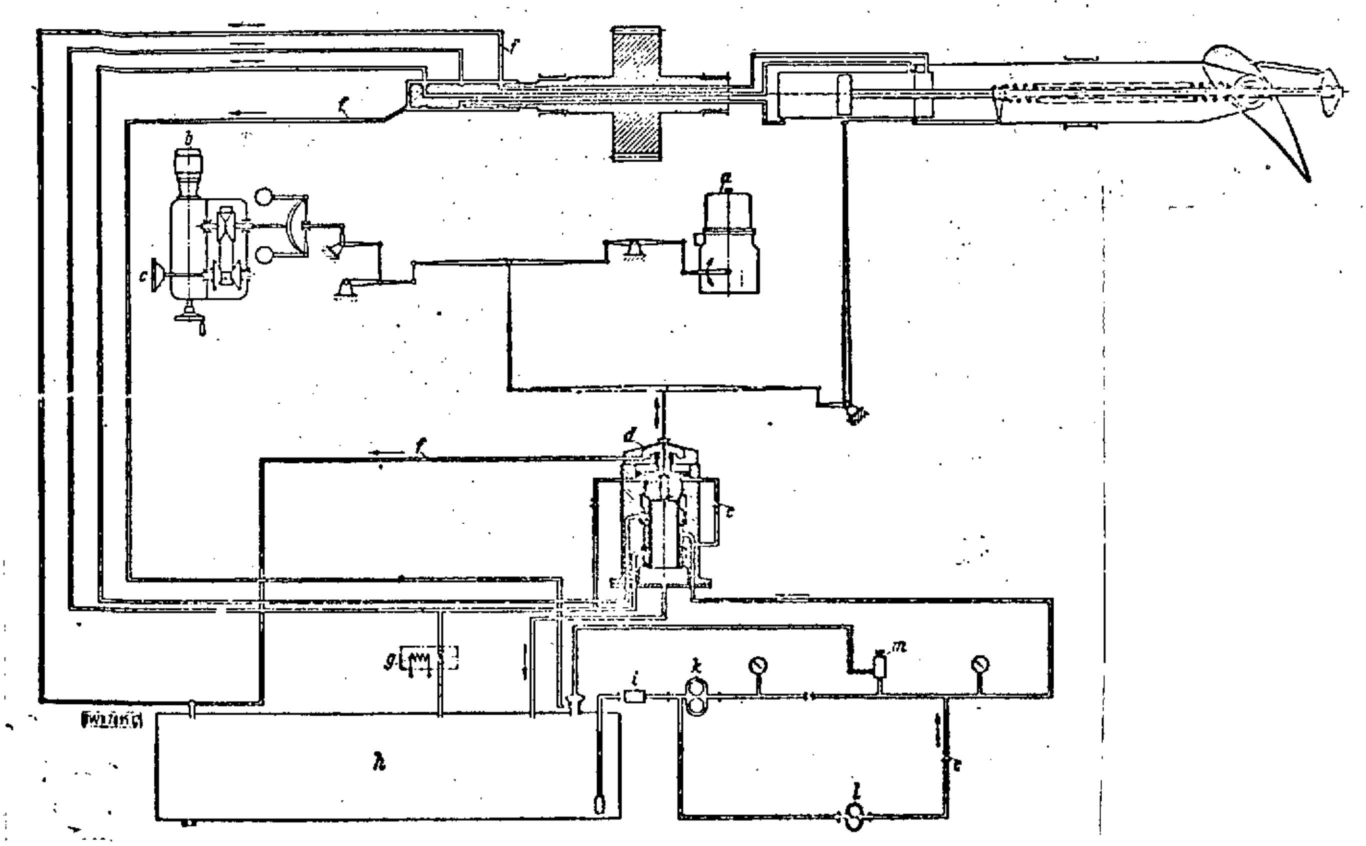


Figure 3. Control System For the Stoetten Experimental Unit. a, Power regulator; b, rpm adjusting drive; c, power from the main drive; d, Voith regulator valve; e, oil pressure control check valve; f, lubication oil; g, magnetic valve; h, oil tank; i, oil filter; k, main pump connected by v-belt drive to the main drive; l, auxiliary pump driven by an electric motor; m, safety valve.

Wind-Power Development in Denmark

Engineer J. Juul, of the South Jutland Electricity Laboratory (SEAS), Huslev, a former collaborator of the Danish Wind-Power Researcher Professor LaCour, resumed his research work after 1950 with a wind power unit of 13 kilowatts in Vester. He put into operation on the island of Boge a three-phase 45 kilowatt power unit with a three-blade assembly 13 meters in diameter. This unit has been working routinely in the utility system for years. With blade placement corresponding to nominal load, its work performance permitted dispensing with direct control over almost the entire range of operation because the current produced "stalling" at the blades when the wind was blowing strongly.

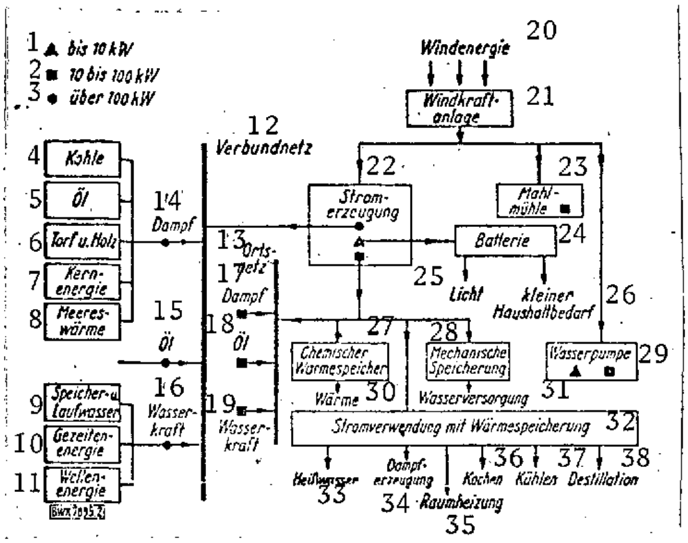


Figure 4. Diagram of Possibilities For Using Wind-Power as Individual Units of in Parallel With a Utility System (According to E. W. Goldring). 1, Up to 10 kilowatts; 2, 10 to 100 kilowatts; 3, over 100 kilowatts; 4, coal; 5, oil; 6, peat and wood; 7, nuclear energy; 8, ocean heat; 9, dammed and running water; 10, tide energy; 11, wave energy; 12, combined system; 13, local system; 14, steam; 15, oil; 16, water power; 17, steam; 18, oil; 19, water power; 20, wind energy; 21, wind-power unit; 22, current production; 23, windmill; 24, battery; 25, light; 26, minor household requirements; 27, chemical energy storage; 28, mechanical energy storage; 29, water pump; 30, heat; 31, water supply; 32, current use with energy storage; 33, hot water; 34, steam production; 35, home heating; 36, cooking; 37, cooling; 38, distilling.

In 1952 the Union of Danish Electric Works founded a wind-power commission in order to continue experiments on a broader basis and to make systematic energy measurements at appropriate places in Denmark. A large 200 kilovolt experimental unit was built near Gedser [1] and was put into operation in 1957, Figure 5. Its tower, made of pre-stressed concrete, is 25 meters high; the three blades are 24 meters in diameter. Figure 6 shows the power curve of the unit at various wind velocities: the efficiency rating was brought up to 63%. The blades begin to turn when the wind blows at 4.5 meters per second. Measurements of blade stresses when operating were made with the support of the British Electrical Research Association (ERA).

As a result of the operational experiments and wind measurements over the entire country, it was determined that it is technically feasable on the west coast of Jutland to produce approximately 1500 kilowatt hours per square meter of blade per year, and on the west coast of the Danish islands approximately 1000 kilowatt hours, that is, to meet the current energy requirements of Denmark of around 4 trillion watt hours, 2.7×10^6 square meters of blade surface would be necessary; approximately 6000 wind-power units, at 200 kilowatts each, could therefore supply all Denmark (about 50 years ago 3000 windmills of approximately the same size were operating in Denmark). If one properly distributed the units over the entire land, one would always have 30% of the nominal power of all the units assured. It would be additionally fortunate for Denmark because wind energy would supplement water energy, and maximum wind power coincides with the time of year, December, when the energy requirements for electrical heating are the greatest.

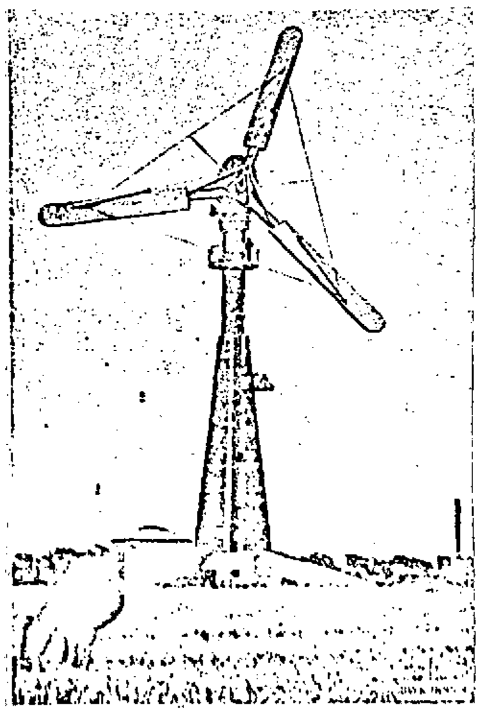


Figure 5. Danish 200 Kilovolt Experimental Unit Near Gedser. a, Blade diameter: 24 meters; b, blade surface: 450 square meters; c, nominal rpm: 30; d, tower height: 25 meter.

Control of an individual unit is restricted to use of brake shutters at the blade tips, which act as auto-controls in emergencies, i.e., when the unit is shut down in a hurricane or in case the electrical connection with the power system is broken. When the wind blows at approximately 5 meters per second the unit begins to run on its own; a centrifical-force relay switches the asynchronous generator into the system as soon as the rpm of the unit is synchronized with the system. When the wind dies down, a reverse-current baffle cuts off the current source. This simple and heavy-duty construction makes it possible to eliminate constant servicing. One of the experimental units ran, for instance, 9 months without servicing, another needed no repairs worth mentioning in 7 years of operation, and it shut itself off during this whole time only twice for a hurricane-strength storm.

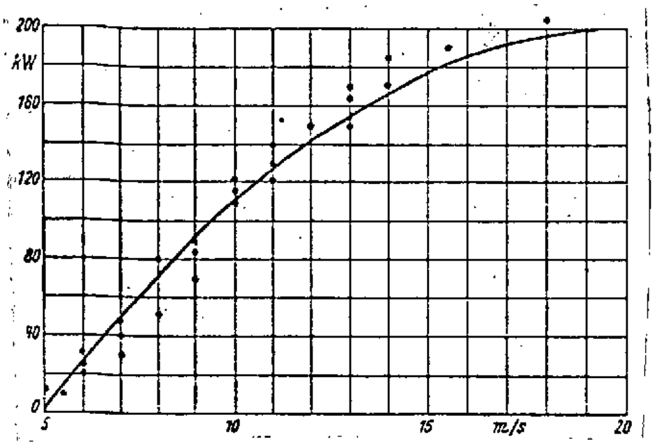


Figure 6. Power Curve of the Experimental Unit in Figure 5.

A large number of units /4 would allow production on a large scale, at which the production cost can be assumed to be approximately 750 marks per kilowatt. The production cost of the kilowatt hours would correspond approximately to those of water power in a mountainous area or that of a modern thermal power plant, but these estimates are only approximate.

Wind-Power Research in Great Britain

In England, research work is in the hands of the British Electrical and Allied Industries Research Association, founded in 1920, in which the speaker, E. W. Goldring of London, plays a leading role. The Association cooperates with and aids the British energy and agricultural ministries as well as the British electric power industry. It is thanks to this circumstance that the research results benefit not only the special area of energy production but also help in other tasks, Figure 7.

It soon turned out that several important considerations of varying type and significance affect prospects of using wind energy:

1. Meteorological problems,
2. efficiency questions,
3. proposal, construction, and use of wind power units,
4. determination of the connection between power and wind velocity, possible annual production under normal working conditions, and life expectantcy of the unit,
5. Proper evaluation of the energy produced in relation to the size of the unit (compare Figure 4).

A systematic meteorological study of the wind conditions along the entire west coast of the British Isles lead to the choice of several hills, the wind conditions of which particularly favored power production and which had a medium to high wind velocity, the main prerequisite for successful operation. The second goal was the development of a failure-free and heavy-duty unit which would need as little servicing as possible at an economical price. The third requirement was the possibility of fully exploiting the energy produced with the least possible expenditure for energy storage.

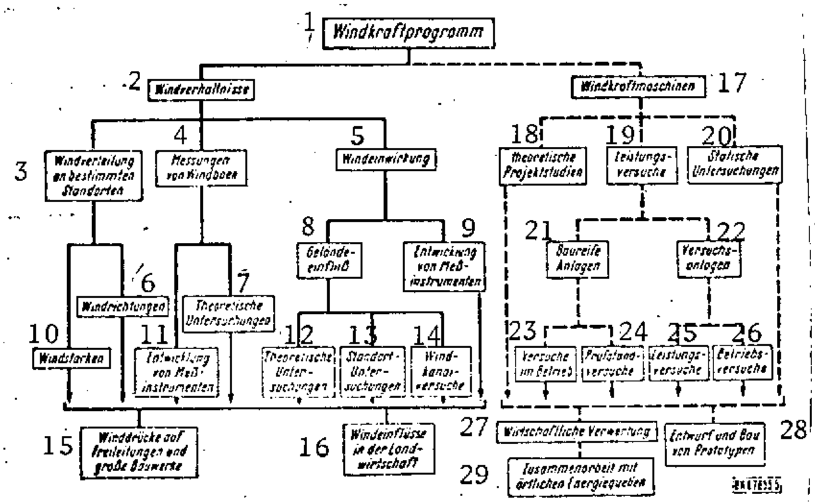


Figure 7. Experimental Program of the British Wind Power Research. 1, Wind-power program; 2, wind conditions; 3, wind distribution to particular areas; 4, wind measurements; 5, wind action; 6, wind direction; 7, theoretical research; 8, influence of landscape; 9, development of measuring instruments; 10, wind strength; 11, development of measurement instruments; 12, theoretical research; 13, area research; 14, wind tunnel experiments; 15, wind pressure on exposed wires and large structures; 16, influence of wind on the landscape; 17, wind power machines; 18, theoretical projection studies; 19, actual construction attempts; 20, static research; 21, ready-to-build units; 22, experimental units; 23, attempts to use; 24, block tests; 25, construction attempts; 26, attempts at use; 27, economic evaluation; 28, proposal and construction of prototypes; 29, collaboration with local energy sources.

As a result of the comprehensive study commissioned by the power ministry, a 3750 kilowatt wind-power unit, Figure 8, was proposed. This was rejected at first as being too expensive, even if the individual unit costs were acceptable. At first, efforts were confined to developing small-capacity prototypes. Then the Central Electricity Authority and the North-Scotland Hydroelectric Board commissioned a 100 kilowatt experimental unit with a blade diameter of 18 meters on the Orkney Islands from the firm of John Brown; this unit provided useful data and survived several bad storms. The two authorities also commissioned the wind-power unit system Andreau [2], which we have already mentioned several times, which also produced 100 kilowatts and was 24 meters in diameters. This was built by the firm Enfield Cables, Limited and was provisionally tested on St. Albans, Figure 9. The unit has been set up since than at Grand Vent near Algiers, where Electricite et Gaz d'Algerie is conducting its own experiments (basically, the depression method of Andreau has proven useful, despite its perforce lower efficiency). Several small 25 kilowatt wind-power units were also designed at the experimental station at Cranfield in the ERA.

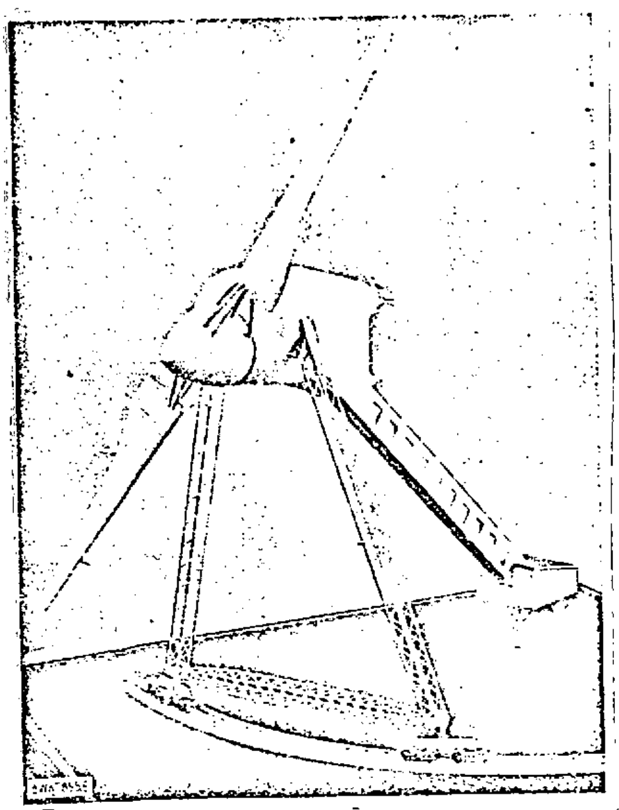


Figure 8. English Project Study of a 3750 Kilowatt Wind-Power Unit.

From the data of the very comprehensive experiments done with all these units, a totally new proposal has emerged, according to which another-100 kilowatt unit is supposed to be built. This would be suitable for large-scale production and should be ready in fall of this year. The speaker presented the following conclusions:

1. A "conventional" type of construction, which would set up the machine with a horizonal shaft on top of the tower, appears to have good prospects as far as operation and economy are concerned. /5

2. The unit should have three or perhaps only two straight blades because such twisted blades cause additional complications and are not worth the additional expense.

3. Despite the stability advantage, which the setting up the unit on the leeward side of the tower provides, the strain on the blade caused by the wind "shadow" of the tower is so great that a unit which holds the tip end of the blade in place by auxiliary wheels in a strong wind probably presents the best solution.

4. Expenditures for larger towers required to raise the blades high enough off the ground are generally not worthwhile.

5. The greatest care is to be given to:

a. A guaranteed start at a low enough wind velocity, and a reliable cut off switch in case of danger;

b. avoiding variations in current due to the rotating masses reaching critical rpm;

c. avoiding swaying of the whole system.

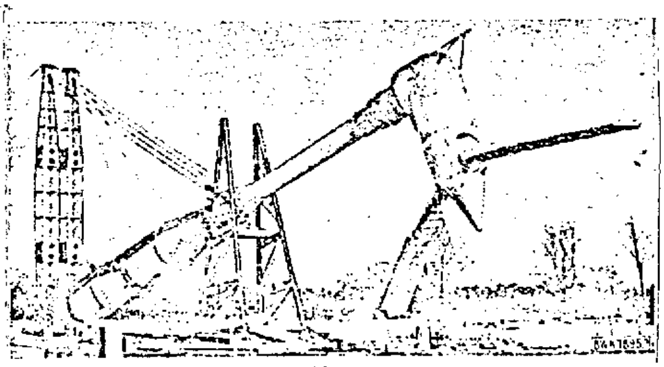


Figure 9. Construction of the 100 Kilowatt Enfield-Andreau Experimental Unit, Near St. Albans (England). On the tip of the blade pointed downwards one can see the air being expelled by centrifigal force. The air turbine at the bottom of the mast is driven by the stream of air. a, Blade diameter: 24 meters; b, nominal rpm: 100; c, tower height: 30 meters.

Construction and Use Results of High-Speed Wind-Power Machines in France

Even the statements of Professor L. Vadot, Grenoble Society for Hydraulic Study and Utilization, showed he basically agreed with the results obtained in other countries. (Electricte de France is now conducting French research work in the area of wind power.)

After explaining the theory of high-speed machines with twisted blades, Professor Vadot first discussed different regulating principles, the automatic feathering control in the form of a directly-connected centrifigal-force pendulum for small units, and the power-driven regulator for larger machines.

The construction of the blades shows developmental tendencies away from all-metal construction to mixed construction (duralumin in skeleton with plastic covering), to making blades of plastic (fiberglass-reinforced polyester resin, at present with a styrofoam core). As an interim solution, the blade form could be considerably simplified without sacrificing efficiency and could thereby be made cheaper to produce (Figure 11).

The results of experiments and theoretical studies have led to new possibilities for improving the efficiency of large units. Especially difficult is the prerequisite, starting at a certain structural size, that the blades, unit, and mast be able to flex. It is also difficult to avoid or to later eliminate this swing, especially when compound flexing occurs.

One experimental unit, Figure 10 and 11, with a nominal power of 130 kilowatts at 12 meters per second wind velocity, 21 meter diameter, and 56 rpm, has been working successfully for 1 year south of Cherbourg and has stood up to several storms with wind velocities up to 35 meters per second without difficulty. At a wind velocity of 12 meters per second, the unit reaches 165 kilowatts. The /6
380 volt asynchronous generator at 150 rpm feeds the public system. Good results were also obtained with medium-sized machines for pumping water.

In an earlier work [3] the speaker had come to the conclusion that units of approximately 300 kilowatts are the most economical for producing power, especially in mass production, with the corresponding cost savings which would then be possible. In contrast to Golding he proposed the 3 blade twisted propellor. He suggests 27 meters for blade diameter and 35 meters for tower height. With an annual average wind velocity of 8 meters per second and an average rpm of 60, average annual output would be 720,000 kilowatt hours. A series of such units, arranged in two lines with equal wind resources, of 1000 and 1250 kilowatt hours per square meter of blade surface per year on the English west coast at a distance of 160 and 140 kilometers, Figure 12, would produce an average annual output of 1.88 trillion hours, if there were a total of 2100 such wind power units operating, with 7 units per kilometer. This amount corresponds to the calculations of J. Juul for Denmark.

Outlook

A comparison of the developmental work in the countries named, and of the data collected over several years of work on the various types of experimental units, shows encouraging unity. As a sign of the advances which have been made, it can be determined that the basic questions posed in an article [4] at the World Energy Conference in Vienna in 1956 can be regarded as answered, to a considerable extent, by the results of the Goepping Wind Power Conference. It has announced as its basic points of view the following:

1. German work in the area of wind-power research is relatively restricted and specialized, but in general correct (since it is concentrated on parallel operation with an already existing power system).

2. The English concept of economical use of wind as an additional source of power in an already existing system can be successful only if the average annual wind velocity is about 6 meters per second and can be regarded as the reason for the limited work in this area in Germany. This is because our country has very few coastal stretches and mountain tops with an annual average wind of more than 6 meters per second. Therefore large-scale economical use in central Europe is possible only in certain windy areas, because of the status of contemporary research.

3. The economical limit of 6 meters per second annual average does not obtain for operation of individual units under special conditions.

4. For system-connected machines, there is a relatively restricted range of possibilities as far as power, blade diameter, and tower height are concerned. The attempt to build large towers and obtain as much power from one unit as possible has turned out to be a mistake. Recognition of this fact further promotes the requirement to simplify the construction, make the units service-free, and produce them on a large scale. The Danish proposals take these points fully into consideration.

5. Despite the discoveries made, final judgements about the economy of system-connected and individual wind-power units have not yet been made. Research must therefore be continued. It appears, however, that it is no longer worthwhile at the present level to continue experiments independently in individual countries. Here, the propositions of L. Vadot and E. W. Golding are worthy of consideration: they want to promote common development and research in Europe and to create an international organization in the form of a loose union. This committee should work out certain common guidelines and make sure that, on offering to build one

of these units for someone interested, the best requirements for selecting the correct location and use of the unit in question are met.

6. Another suggestion from Golding dealt with an international wind-power conference and exhibition which could be organized, for instance, by the United Nations in order to open up these possibilities, especially for underdeveloped countries.

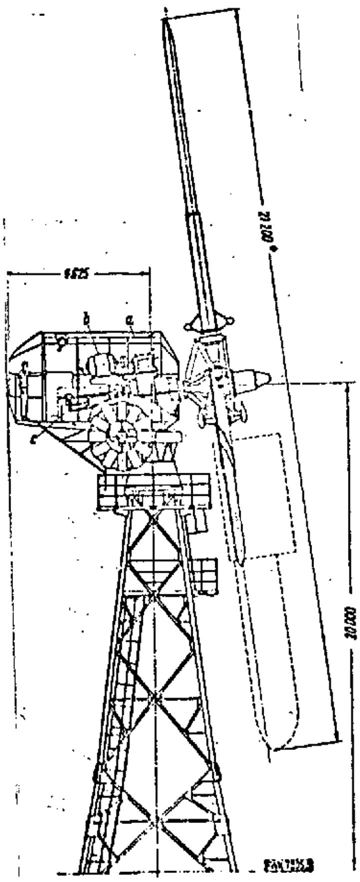
One feels, therefore, that the time is right to bring thoughts about using wind power before the public. We will have to make sure in this process that the two basically different areas of usage, for individual supply and supporting country-sized or state-sized systems, are clearly distinguished from one another from the beginning.

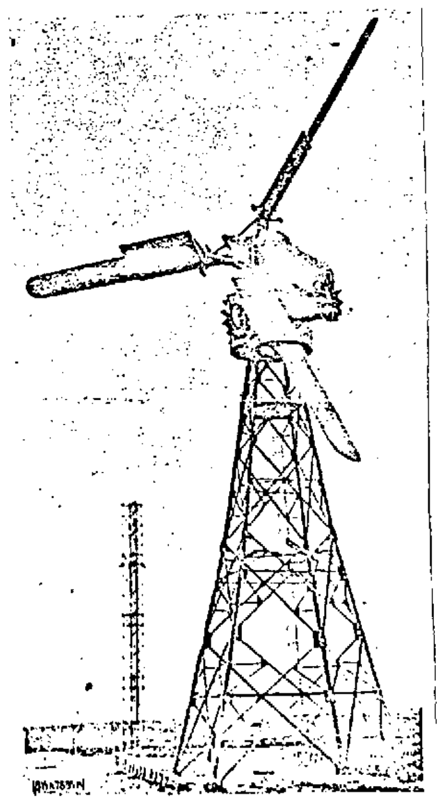
Underdeveloped countries would probably be most interested in individual units (or they could be interested), but not industrialized areas or even farm areas of countries with a high standard of living. The conference only briefly touched on this problem, nevertheless the proposition made there, that the farmer should and could orient his work day to a certain extent according to the wind, can only be accepted with great reservations. It is definitely a fact that there is a difference whether it is a project for Central Africa or for Schleswig-Holstein. Therefore, we consider the question of standard of living completely decisive in regard to individual energy supply units.

The issue of cost is another matter. In the areas still without electricity or on isolated farms, practically the only competition would be the diesel engine. Except for places where daily current from diesel fuel is impractical or too expensive, even a diesel unit only needs a battery to supply a large farm. However, in contrast to a wind-power unit it needs constant servicing, and must be housed in a solid building.

Nuclear energy cannot even be considered for supplying individual customers.

In supplying large numbers of people and also supporting existing power systems, on the other hand, the kilowatts produced by wind energy must be able to compete with the systems power. The fact that this has recently become possible and that the technical requirements have already been met to a great extent, was shown at the conference. Golding named a production figure of 600 marks per kilowatt in large-scale production for the 100 kilowatt English machine now under construction. If the units last long enough, then such wind-power units will also be able to compete in Central Europe - provided the wind holds! -





Figures 10 and 11. French Experimental 130 Kilowatts Nominal Unit Neyrpic D-21 Power. 1, Blade diameter: 21 meters; 2, nominal rpm: 56; 3, tower height: 20 meters. a, Drive works; b, three-phase current production; c, servomotor.

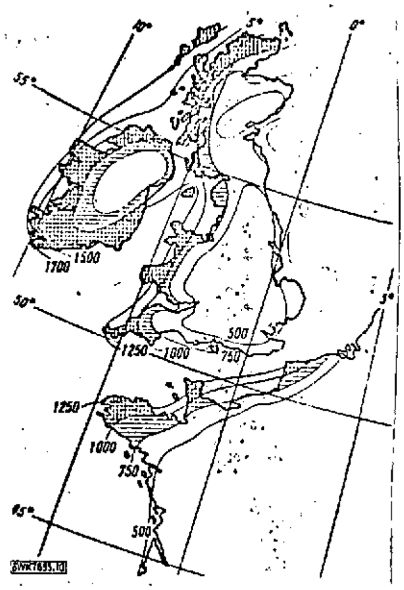


Figure 12. Wind Chart of the Northwest European Coastal Area. Areas of equal wind resources in kilowatt hours per square meter of blade surface per year. Blank areas: 1000 kilowatt hours per square meter per year with a 27 meter blade diameter. Darkened areas: over 1000 kilowatt hours per square meter per year with a 21 meter blade diameter.

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